Hollow Cathode Assembly Development for the HERMeS Hall Thruster

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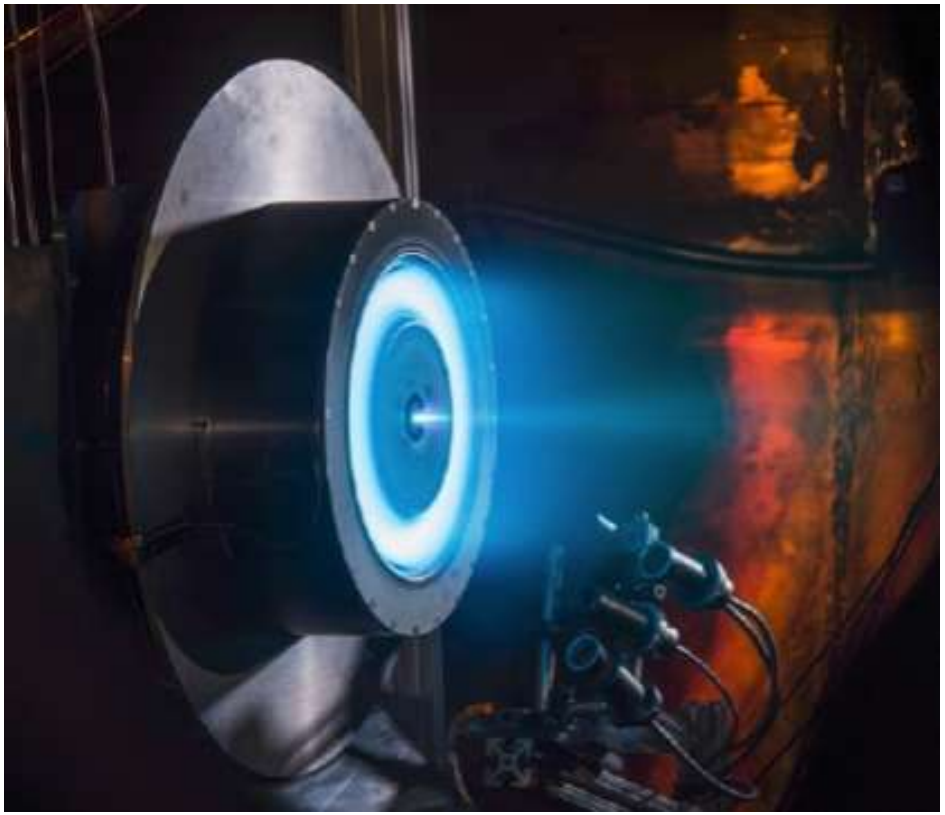
Presentation Outline

- **Introduction**
- **Cathode Development Approach**
- **Cathode Characterization Test Results**
- **BaO Cathode Wear-Test:**
  - Cathode Configuration
  - Wear-test Configuration
  - Wear-test Performance Results

Introduction

- **HERMeS Thruster Development for Asteroid Redirect Robotic Mission (ARRM)**
  - Each 12.5 kW HERMeS Hall thruster on spacecraft will be required to process ~1800 kg of Xenon
  - Hollow cathode required to provide 8 – 32 ADC for 34,000 hours
  - Two emitter technologies are being investigated
    - Lanthanum Hexaboride (LaB6)
    - Barium-based impregnated (411, BaO)



Hollow Cathode Emitter Technology Assessment

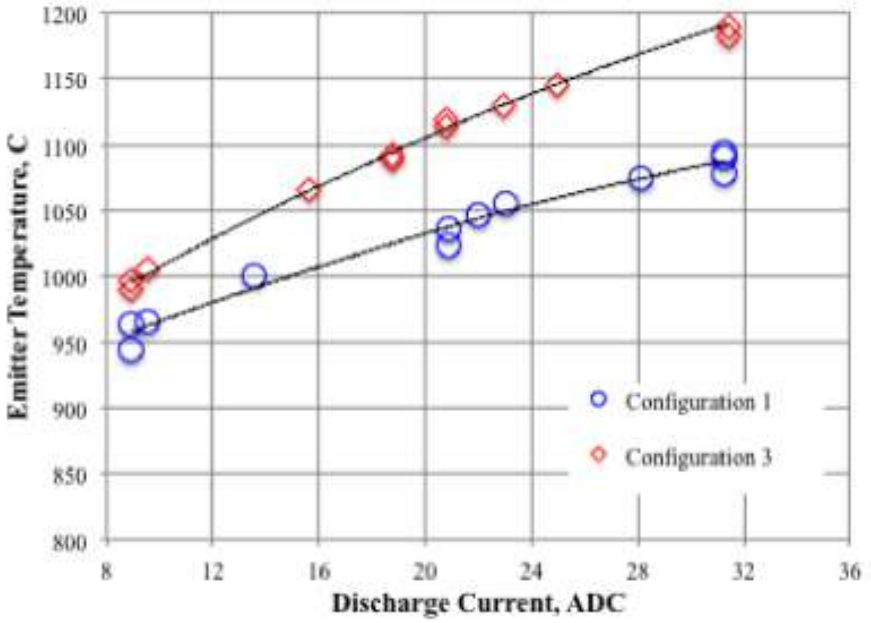
- Hollow Cathode capability assessed through three activities
  - Cathode Testing
    - Characterization testing to determine temperature & plasma properties to identify cathode configuration to support thruster testing
    - Wear-testing of hollow cathodes at thruster operating conditions
    - LaB6 heater life testing to validate heater reliability
  - Develop mature cathode assembly design for HERMeS thruster
    - Detailed design of hollow cathodes compatible with HERMeS completed
      - Analyzed structural and thermal behavior
      - Prepared for environmental testing of completed units
  - Assess systemic benefits and consequences of use of emitter options
    - Quantify benefits of LaB6 emitter resistance to propellant oxygen contamination
- Cathode emitter option down-select & recommendations expected to be completed by end of Summer 2016

Characterization Testing – BaO cathode results

- **Cathode operating behavior measured:**
  - Emitter temperature measured with internal optical probes
  - Cathode plasma properties measured with probes internally installed
- Cathode Orifice Size options investigated

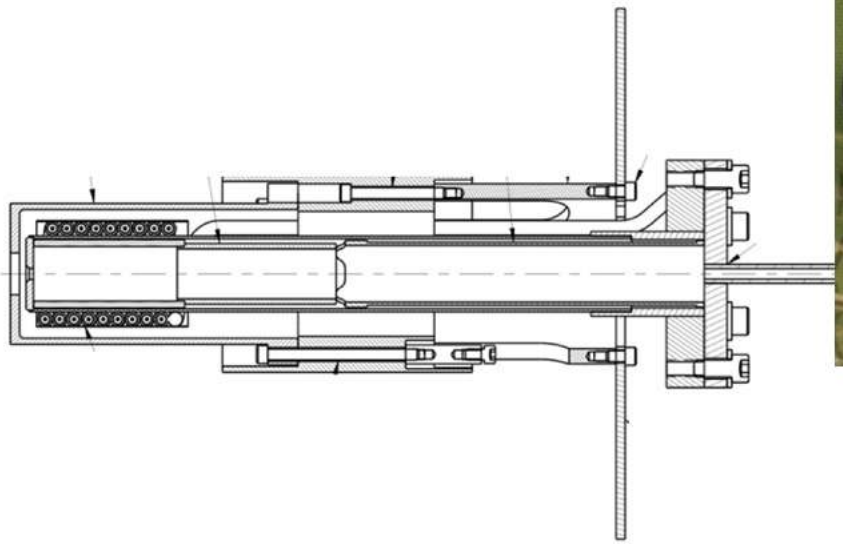
Configuration	BaO	LaB6
1	100%	100%
2	83%	158%
3	58%	

  - **Results:**
    - Configuration 1 temperature behavior represented best match for stable operation and margin
    - Plasma measurements showed broad plasma distribution on emitter interior



Cathode Configuration for Wear-test

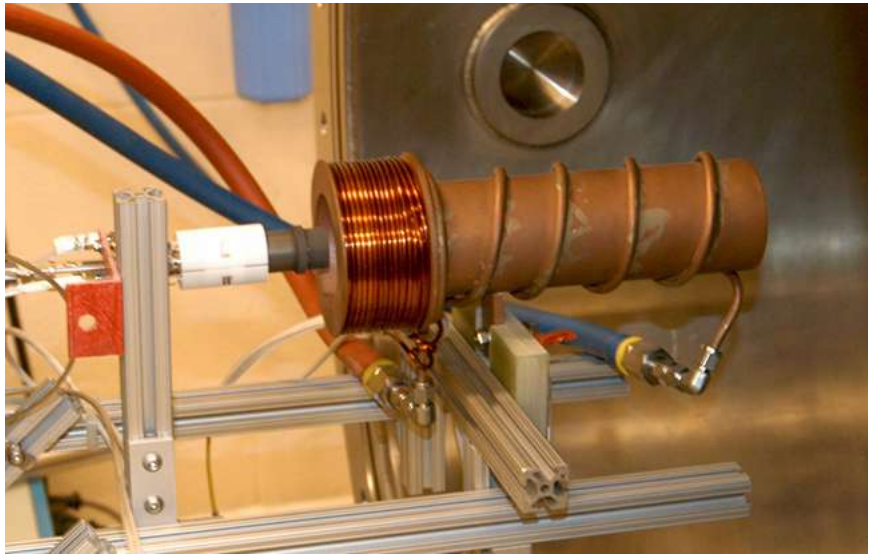
- Cathode Assembly Breakdown:

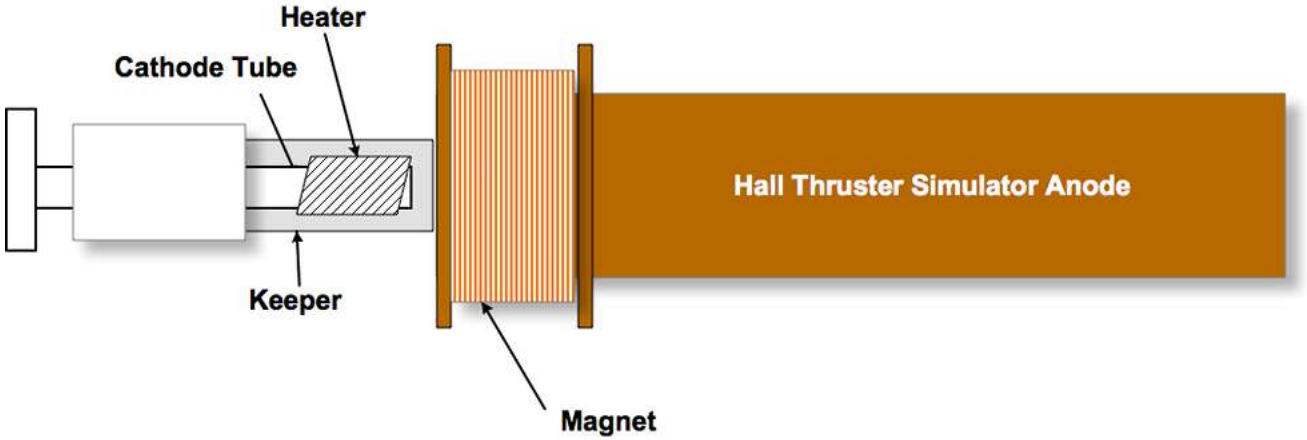


- Development cathode allowed rapid changes for characterization testing while being compatible with HERMeS TDU thrusters

Thruster Simulator Anode

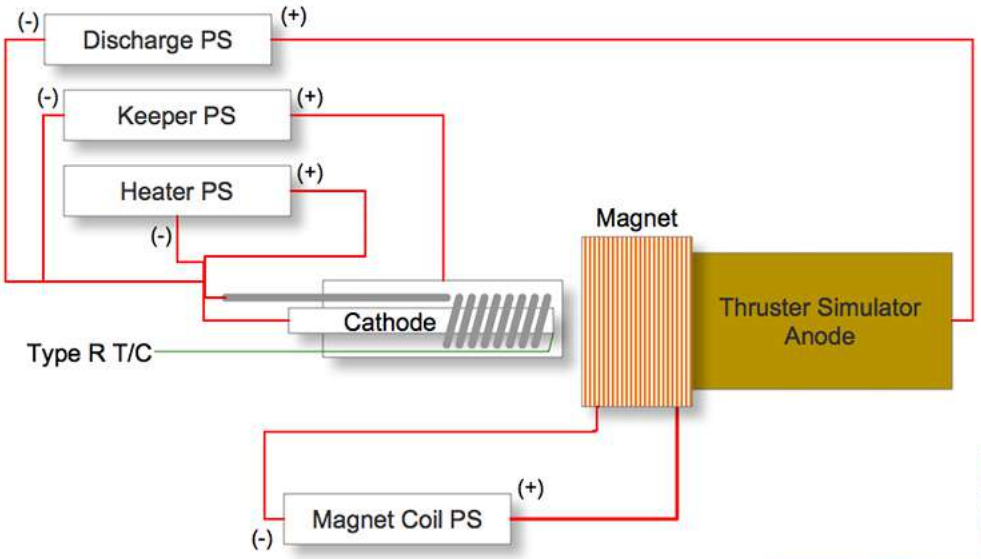
- Anode incorporates magnetic coil to simulate the equivalent field magnitude imposed by HERMeS thruster magnet coils when operating at nominal run condition
- Mikellides & Goebel have verified simulator design represents HERMeS thruster





Cathode West-Test Set-up

- Electrical Configuration



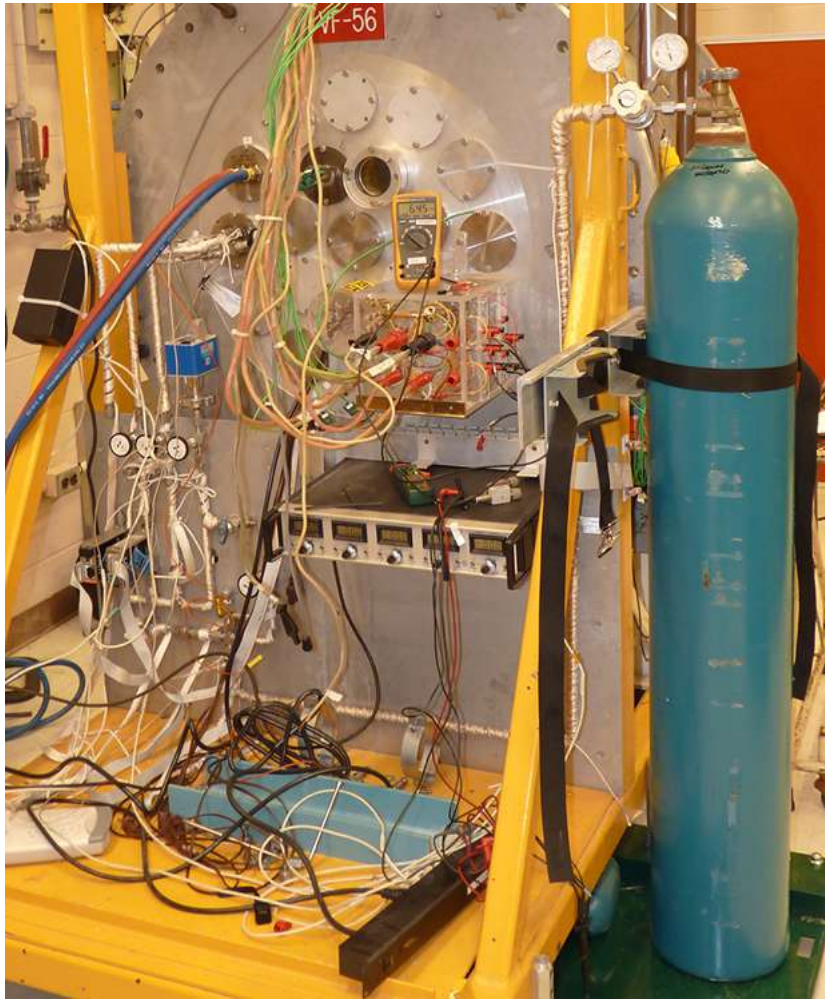
- Data Acquisition System
  - Data logger connected to software on computer for data monitoring and display
  - Interlocks enabled in software that disables power supply operation in event of limit trip

Wear-test Facility

- VF-56 Test Facility
  - 1.0 m dia X 1.0 m L
  - Cryo-pumped – 2 x 10^{-6} Torr base, 10^{-4} Torr at run condition

Xenon Feed-system

- **Cleanliness Requirements:**
  - 99.9995% purity xenon
  - Feed-system integrity verified by bake-out & leak-rate testing
    - Per GRC procedures developed for past qual/flight programs
  - Point-of-Use Purity test
    - Collected xenon gas sample for verification by commercial vendor
    - Feed-system passed for all contaminants

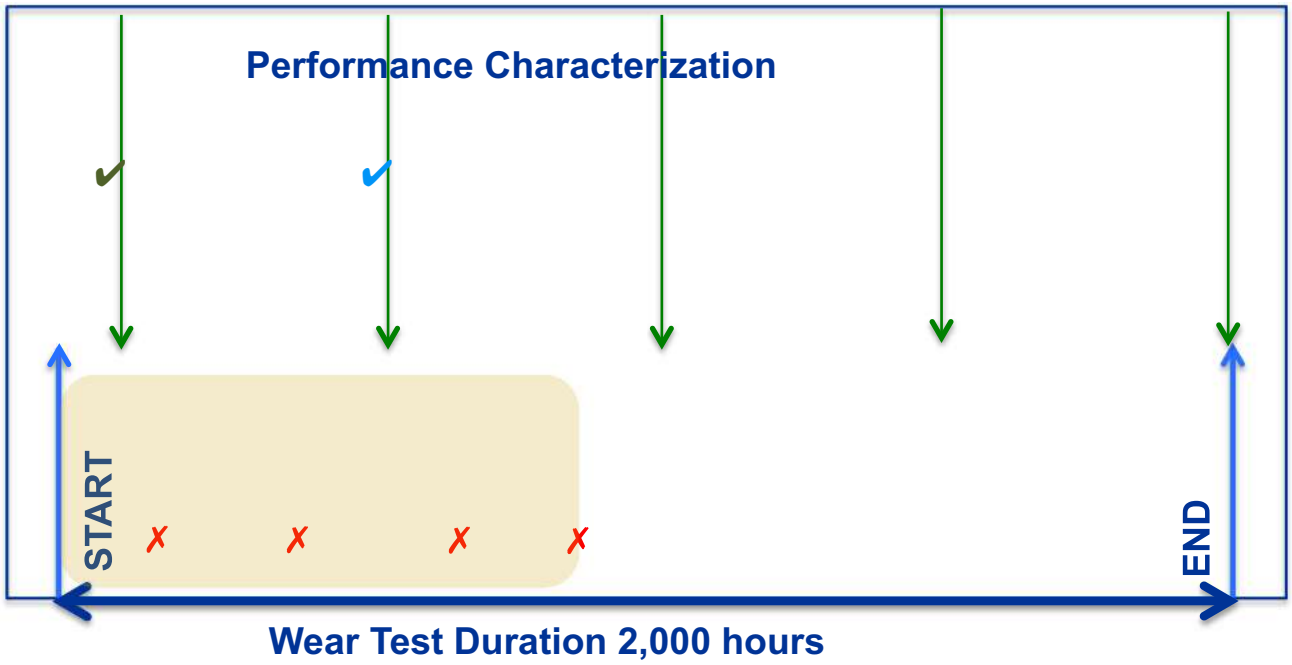


Cathode Operating Conditions

- **Steady State:**
  - Discharge Current = 24.8 ADC
    - Incorporating corrections for thruster effects
  - Mass Flow Rate = 1.45 mg/s (14.7 sccm) (7% condition)
  - Keeper current = floating
  - Magnet Current sufficient to generate 180 G field on anode centerline
- Similar conditions as cathode operating in TDU-1 2000 wear-test
- **Data measured**
  - Voltages – discharge, keeper (powered/floating), magnet coil
  - Currents – discharge, magnetic, keeper
  - Mass flow rate
  - Cathode orifice plate temperature
  - AC behavior: discharge voltage, keeper voltage, discharge current
  - Facility Pressure

Wear Test Timeline & Progress

- **Wear-test initiated 5/20/2016**



Legend:
X = unplanned interruptions
√ = performance characterizations completed
Green arrow = planned characterizations

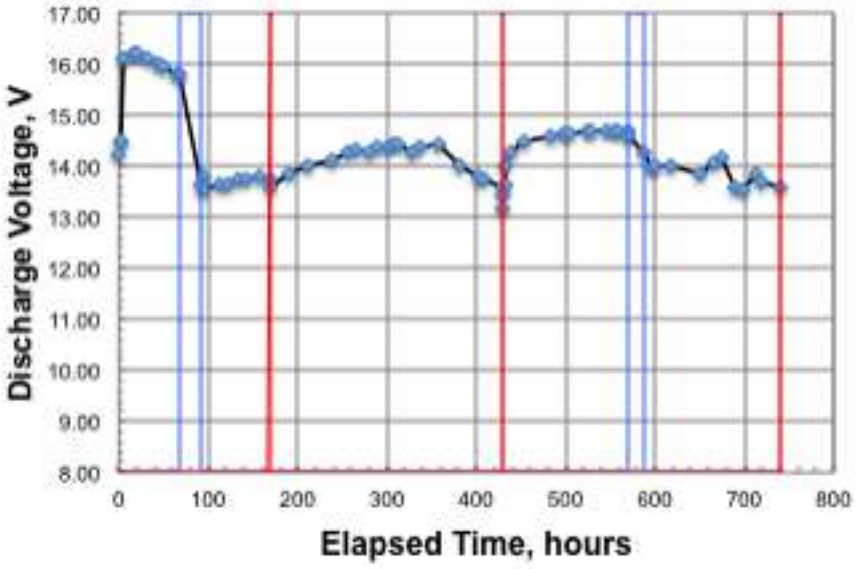
Cathode Performance Characterizations

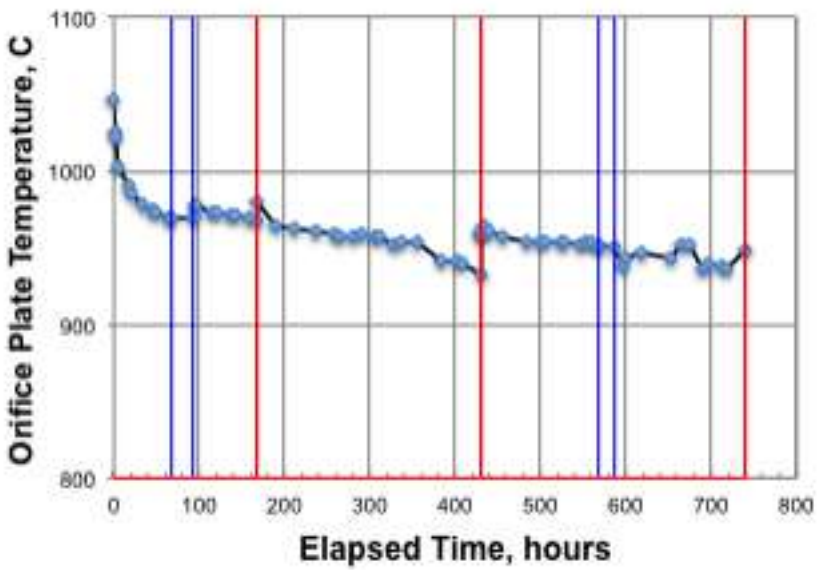
- Parametric Sweep to check cathode operation over entire range
  - Limited operation where necessary – discharge voltage ≤ 30 V
  - Keeper-only operation to provide common check points with cathode performance in thruster
- Characterizations performed every 500 hours

Discharge Current, A	Keeper Current, A	4.6	6.4	10.6	13	14.7	16
6.2	0, 2						
15	0						
22.1	0						
24.8	0						
27.3	0						
31.3	0						
0	3*						
0	2*						

Cathode Operation to Date

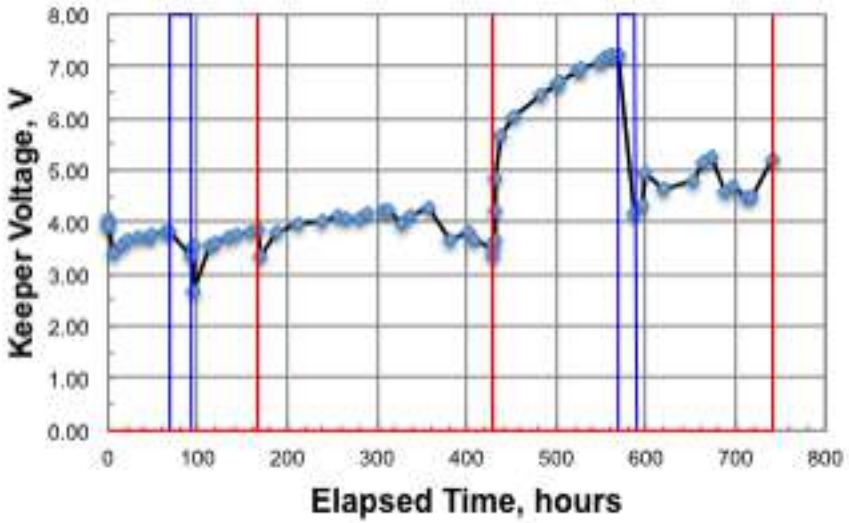
- Discharge voltage, cathode tip temperature have been stable
  - Voltage = 14.3 V nominally
  - Temperature = 962 °C
    - Temperature measured with type thermocouple spot-welded to cathode tube at orifice plate weld
    - Decaying temperature may be attributable to changing contact conditions





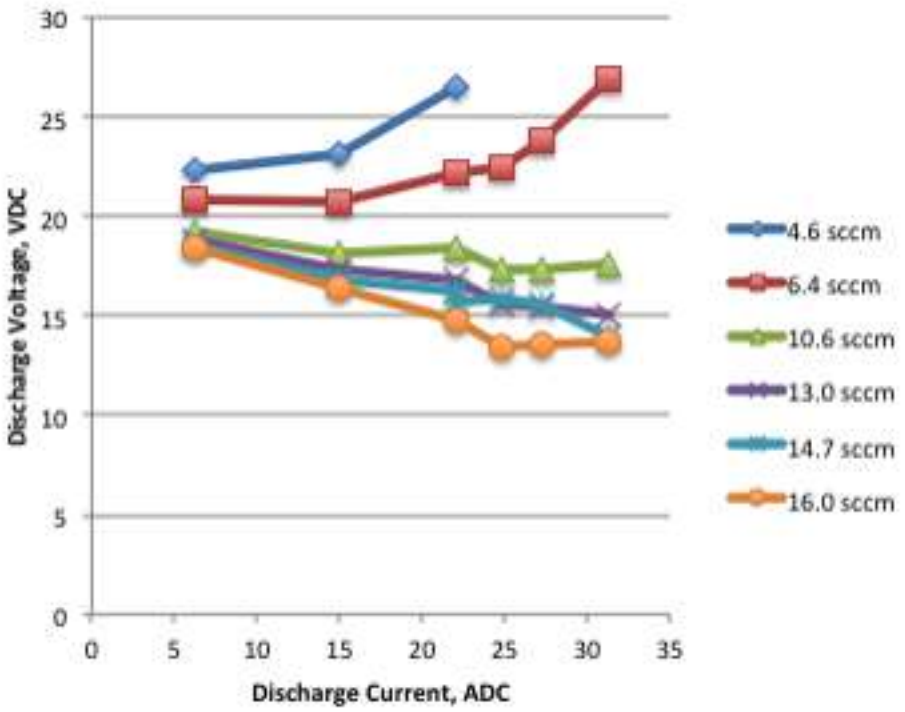
Cathode Operation to Date (cont'd)

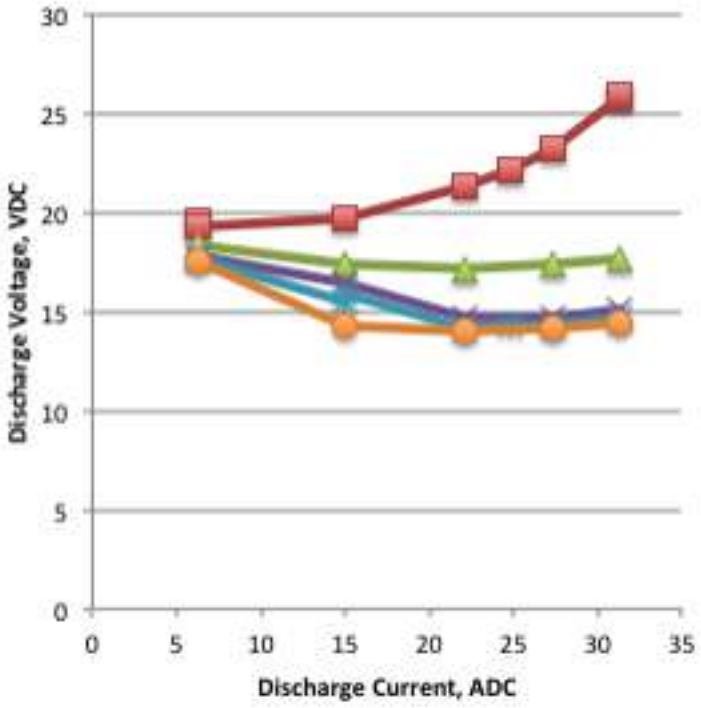
- Keeper Voltage measurements showing variation
  - Changes with test interruptions suggest changes in keeper surface conditions may be factor
    - Facility regeneration at hour 430 may have lead to oxide coating
    - Recovery after performance characterization may indicate removal of coating



Performance Characterization Results

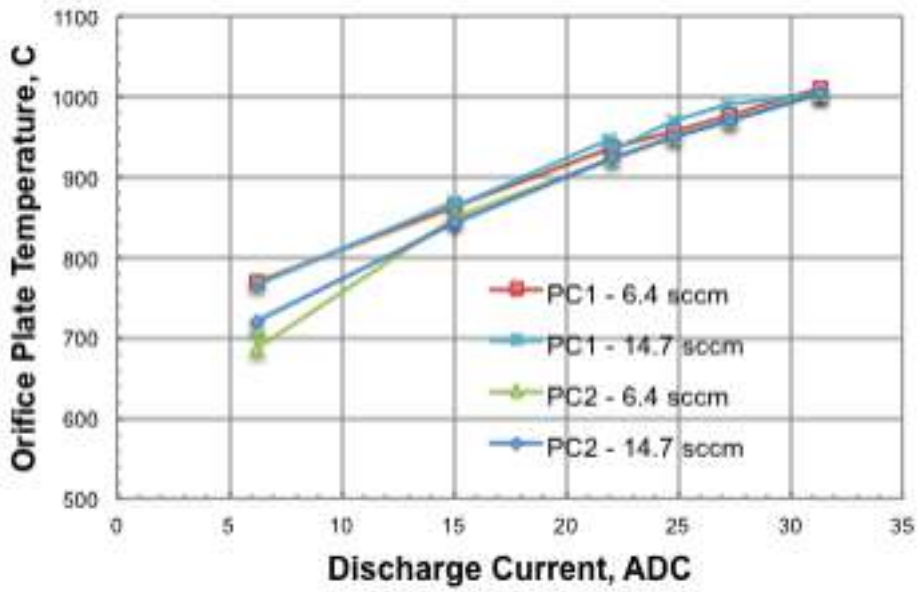
- Discharge voltage exhibited agreement between characterization checks





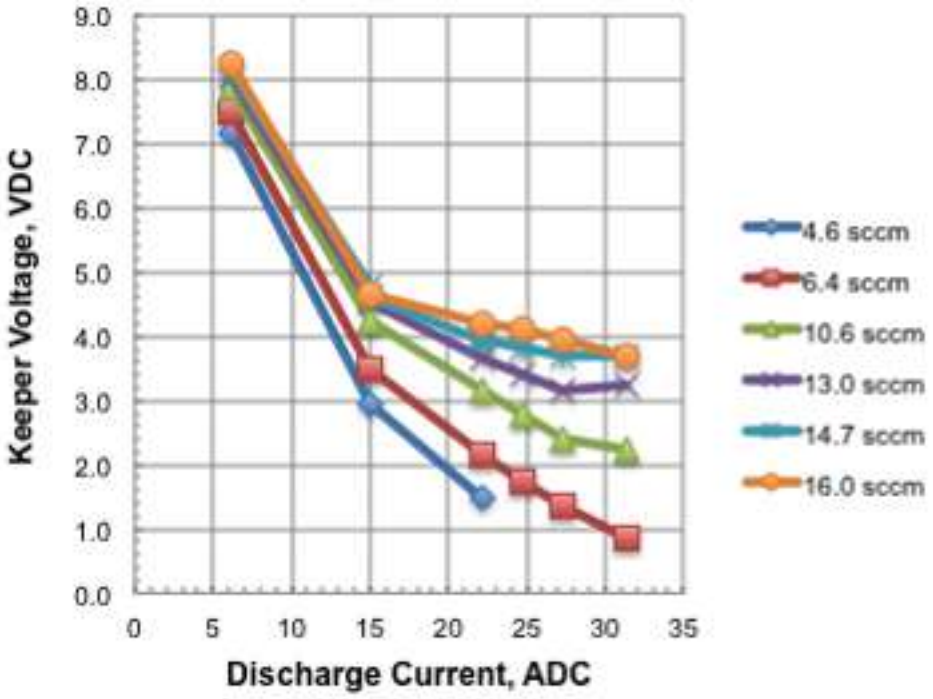
Performance Characterization Results (cont'd)

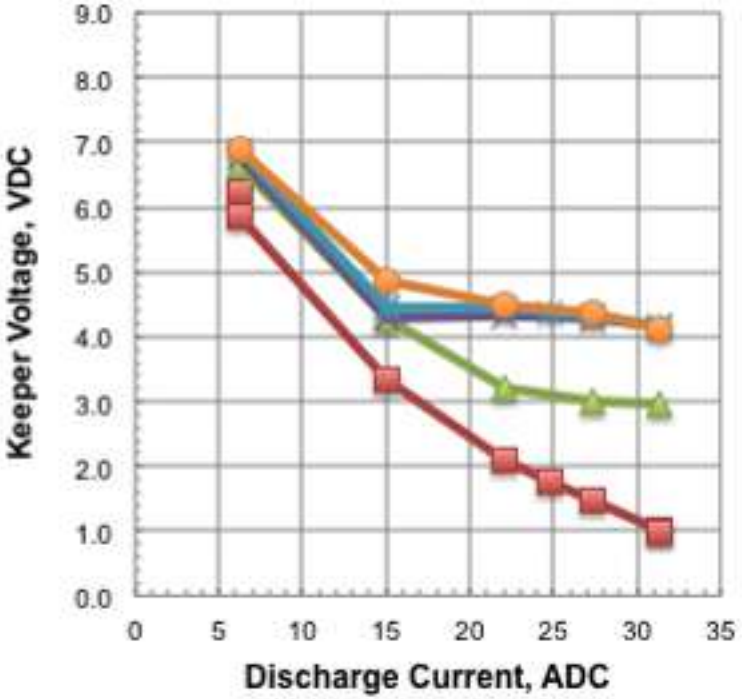
- Cathode tip temperature exhibited agreement between characterizations
- Insensitive over flow range



Performance Characterization Results (cont'd)

- Periodic checks over operating range showing consistent behavior





Summary Remarks

- Cathode assembly assessment and development activities are underway to support long-life operation for HERMeS thruster
- Combination of testing, high fidelity cathode assembly design, and system-level integration assessments is being pursued to determine emitter option for use in HERMeS thruster
  - Down-select to be completed by end of this summer
- BaO Cathode Assembly is being wear-tested in dedicated facility at VF56
  - Same conditions as cathode operating in HERMeS TDU-1 thruster being wear-tested at GRC
- Cathode operating parameters have been stable
  - Keeper voltage variation appears related to test interruptions (coating possible culprit)
- Upon completion of 2,000 hour test, cathode condition will be assessed for any thruster-specific wear mechanisms
  - TDU-1 hollow cathode will also be examined